Dairy Cow Thermal Balance Model

Heat Stress Prediction for Cows on Pasture

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Motivation and Goals

Context

- Highly productive dairy cows are sensitive to high temperature and humidity because of high metabolic heat production in the rumen
- When cows become heat stressed, feed intake is reduced and milk production declines
- Heat stress can lead to poor reproductive performance
- Severe heat stress can cause increased death losses
- Producers typically assess climatic conditions by monitoring air temperature and relative humidity which is combined in the temperature humidity index (THI)
- THI does not take into account two important factors that affect grazing dairy cow heat stress:
    - Solar radiation and
    - Wind speed

www.montrosedairy.com

www.naturesfinestseed.com/pasture-seed/cattle/dairy-cow/great-plains-dairy-cow-forage-blend

Objectives

- Develop a spreadsheet that solves the heat balance model published by McGovern and Bruce (2000) describing respiratory, convective, short-wave and long-wave radiant and evaporative heat transfer from the cow's body to the surrounding environment
- Asses cow responses to different ambient environments

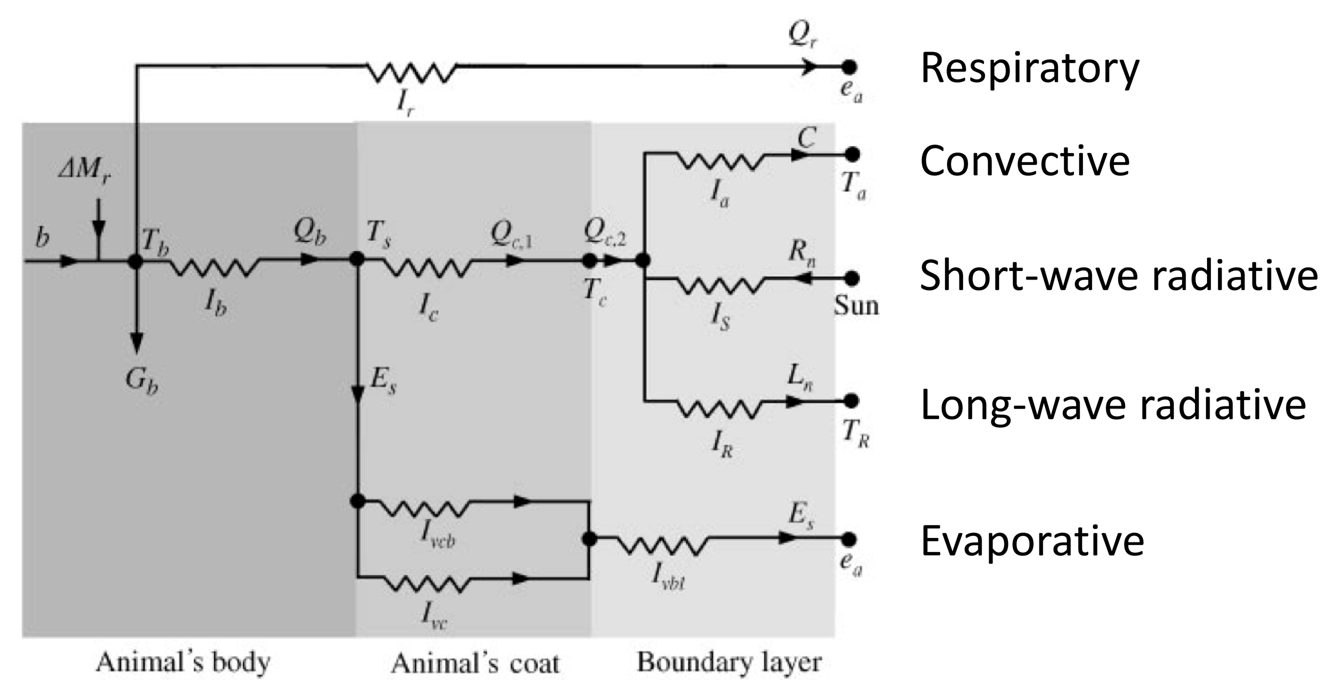
Responses to Heat Stress

- Dairy cows minimize heat stress effects by changing:
    - Tissue thermal resistance (Case 1)
    - Sweat rate and evaporative heat losses (Case 2)
    - Respiration rate (Case 3)
    - Body temperature and heat storage (Case 4)

The Model

Electrical Analog Illustration

Heat exchanges between the cow and ambient environment



McGovern and Bruce (2000)

Modeling Responses to Heat Stress

	Case #			
	1	2	3	4
Air temperature, T_a (°C)	-10	15	30	40
Metabolic production, M (W/m²)	166	166	166	166
Respiratory heat loss, Q_r (W/m²)	48	33	78	88
Stored heat, G_b (W/m²)	0	0	0	**78**
Evaporative heat loss, E_s (W/m²)	106	**100**	**127 (max)**	**87 (max)**
Convective heat loss, C (W/m²)	73	72	44	27
Coat heat flux, Q_c (W/m²)	12	33	-39	-87
Respiration rate, r (breaths/min)	12	12	**78**	**86 (max)**
Body temp rise, ΔT_b (°C/hr)	0	0	0	**0.90**
Tissue resistance, I_b (m² °C/W)	**0.25**	**0.02 (min)**	**0.02 (min)**	**0.02 (min)**

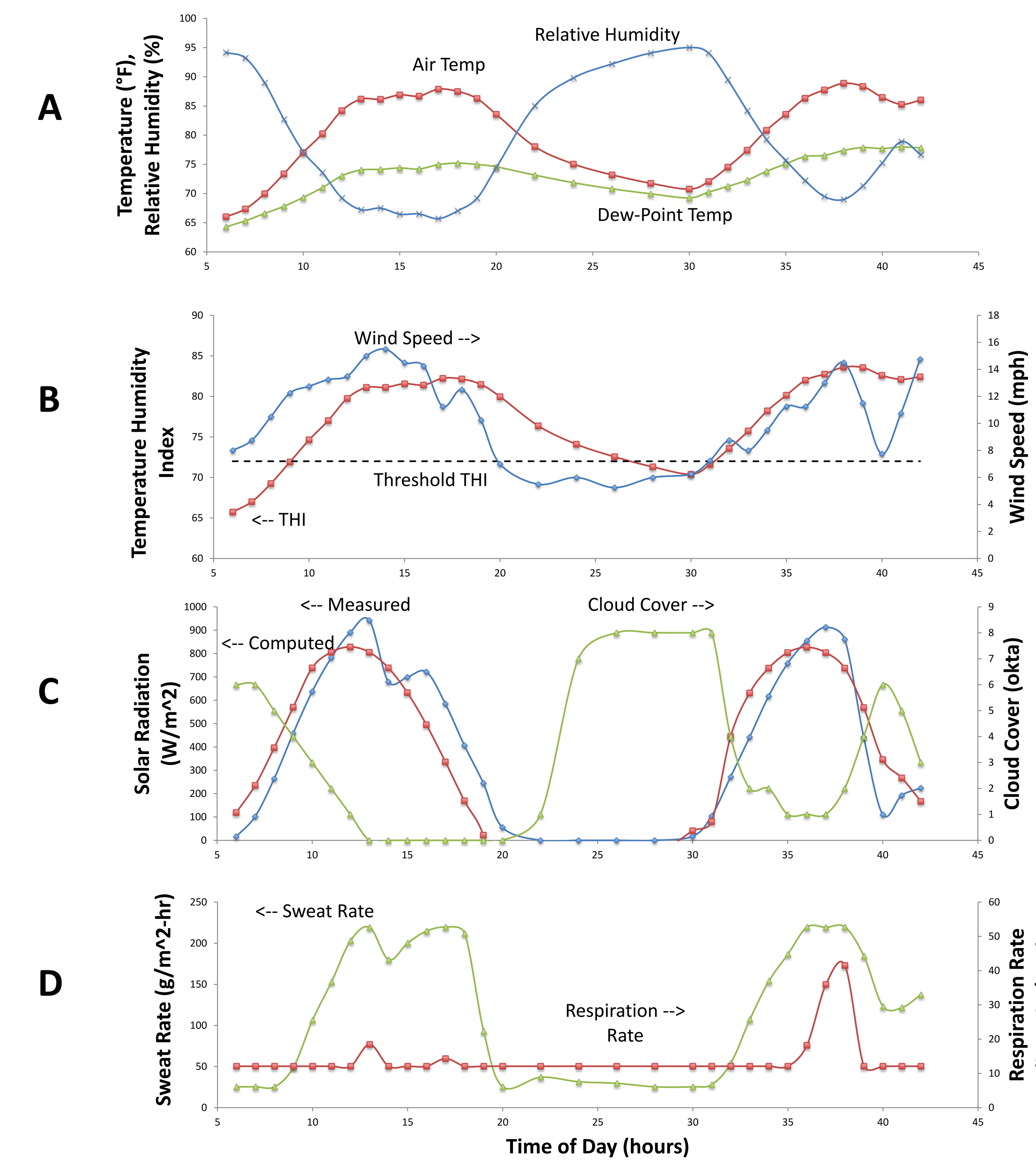
Case descriptions

- Case 1 illustrates a cow in a cold environment where she maximizes tissue resistance to maintain body temperature
- Case 2 illustrates a warmer environment, where tissue resistance has been minimized and sweating alone balances heat flows
- Case 3 illustrates a higher temperature requiring an increased respiration rate when the cow is sweating at a maximum rate
- Case 4 illustrates more heat stress when a cow is at maximum sweating and evaporation rate and the need for the cow to increase her body temperature and store heat

Heat stress mitigation with 50% shading

- Reduces respiration rate in Case 3 by 40%
- Reduces body temperature rise in Case 4 by 30%

Model Inputs and Outputs



- Figures A, B and C give model inputs from West Central Research and Outreach Center, Morris, MN for July 20-21, 2014.
- Figure D gives the calculated sweat and respiration rates

Conclusions

1. Model effectively describes heat transfer between cow and ambient environment in hot weather
2. Model results indicate that
    a. Sweating begins to increases when THI crosses the threshold THI of 72
    b. Respiration rate begins to increase after sweat rate reaches maximum
3. A combination of high THI and solar radiation leads to increased respiration rates